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Debris Disk Science with the Palomar ExAO System : First Results

Matthew Wahl[1], Stanimir Metchev[1], Rahul Patel[1], Eugene Serabyn[2], Dimitri Mawet[6], Richard Dekany[3], Jennifer Roberts[2], Rick Burruss[2], Antonin Bouchez[3,4], Tuan Truong[2], Christoph Baranec[3], Stephen Guiwits[2], David Hale[3], John Angione[2], Thang Trinh[2], Jeffry Zolkower[3,5], J. Christopher Shelton[2], Dean Palmer[2], John Henning[3], Ernest Croner[3], Mitchell Troy[2], Dan McKenna[3] and Jonathan Tesch[2]

[1]Dept. of Physics and Astronomy, Stony Brook University, Stony Brook, NY 11794
[2]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Blvd., Pasadena, CA 91109, USA
[3]Caltech Optical Observatories, California Institute of Technology, 1200 E. California Blvd., MC 11-17, Pasadena, CA 91125, USA; rgd@astro.caltech.edu
[4]Now at Giant Magellan Telescope Observatory Corp., Pasadena, CA 91106, USA
[5]Now at Department of Astronomy, Cornell University, Ithaca, NY 14853, USA
[6]European Southern Observatory (ESO), Alonso de Cordova 3107 Vitacura, 763 0355, Santiago, Chile

Abstract. We present first imaging results from the PALM-3000 adaptive optics system and PHARO camera on the Hale 5 m telescope. Observations using a vector vortex coronagraph have given us direct detections of the two-ring dusty debris system around the star HD 141569. Our observations reveal the inner clearing in the disk to unprecedentedly small angular separations, and are the most sensitive yet at the H and K bands. We are for the first time able to measure and compare the colors of the scattered light in the inner and outer dust rings, and find that the outer ring is significantly bluer than the inner ring.

1. Overview, Data and Analysis

Images of the dusty debris disk around HD 141569 were obtained with PALM-3000 adaptive optics system and PHARO camera on the Palomar 5 m telescope in June 2012. HD 141569 is an A0 type Herbig Ae star located at 99 ± 8 pc (Van Leeuwen 2007) with an age of roughly 5 Myr. The PHARO camera contains a hard edged Lyot coronagraph for high-contrast imaging, and as of 2009, a vector vortex coronagraph (Mawet *et al.* 2009). The vector vortex coronagraph works by inducing a phase change to incident on axis light causing it to interfere with itself destructively inside the pupil, thus nulling it.

Observations of a reference star, HD 142864, were carried out so that accurate point spread function (PSF) subtraction can be achieved. We integrated for 1.0 hr on target, for each band, and 0.5 hr on the calibrator star. The data were analyzed using Karhunen-Loeve Image Processing (KLIP; Soummer *et al.* 2012) which performs principle component analysis. Our images resolve the known two-ring structure of the disk, and are the most sensitive to date in the H and K bands.

2. Results

We observe an inner clearing from $\sim 0\farcs5$ (50 AU) out to the edge of the inner disk at $1\farcs77$ (177 AU). The inner disk is $0\farcs64$ (64 AU) wide and extends out to $2\farcs41$ (241 AU).

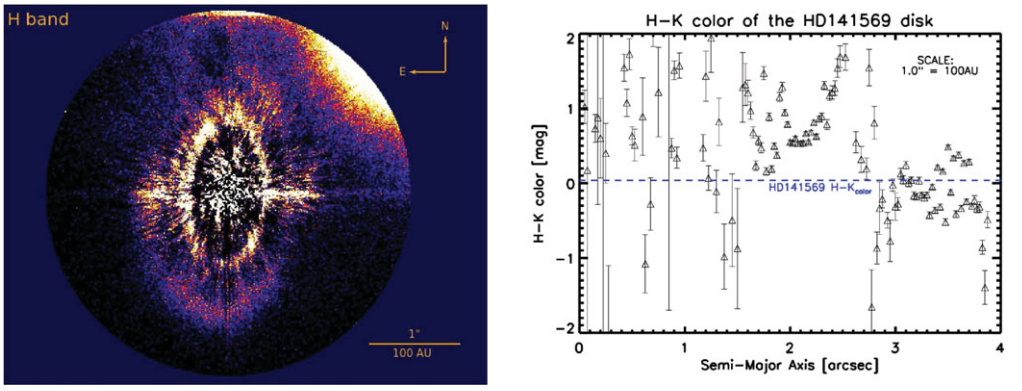

Figure 1. Left : Image of HD 141569 taken in the H band. The two known rings are visible, and there is an extra feature to the east between them. It is characterized as emission at $1\overset{''}{.}5$ extending from a PA of 30^o to 98^o. **Right :** H-K Color plot of the two rings showing that the inner ring is noticeably redder than the outer ring. Our data reduction with KLIP, while optimized for revealing the extended emission from the disk, incurs a dark hole of non-astrophysical negative residuals around the star. As a first-order attempt at removing this effect, we fit a line to the minimum residual emission as a function of radial separation.

The outer disk has emission from $3\overset{''}{.}06$ to $3\overset{''}{.}87$ (306 AU to 387 AU) with a width of $0\overset{''}{.}81$ (81 AU). Both are offset from the central star by measurable amounts, but do not share a common center.

There is also an obvious gap between the two disks, which may be cleared by a forming exoplanet. The gap has alternatively been interpreted as part of a spiral structure formed from perturbations by HD141569 B and C (Clampin *et al.* 2003, Quillen *et al.* 2005, Ardila *et al.* 2005, Wyatt 2005) whose PSF wings are visible in the north-west corner of Fig. 1.

The H-K disk color in Fig. 1 was inferred from the the H and K_s band surface brightness profiles (SBPs) of the HD 141569 debris disk. There are two peaks in the SBPs, one at $2\overset{''}{.}0$, and the other, less prominent between $3\overset{''}{.}3$-$3\overset{''}{.}6$ correspond to the mid-ring semi-major axes of the two circumstellar rings. Our data lose sensitivity inwards of $0\overset{''}{.}8$, although for the first time we can rule out $> 3\times$ brighter rings inwards to $0\overset{''}{.}5$. Another new result is the determination of the near-infrared color of the circumstellar disk. In particular, the outer ring is 0.5–1.0 mag bluer than the inner ring.

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